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EAST93 - GEOPHYSICAL TRAVERSE FROM THE TRANSANTARCTIC MOUNTAINS TO THE WILKES BASIN, EAST ANTARCTICA

A Joint United States - New Zealand Science Project

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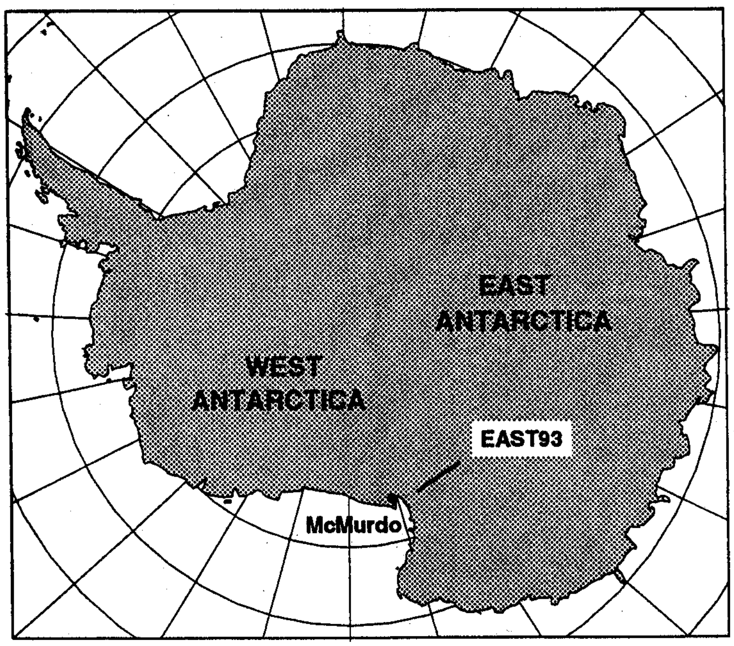

U.S. GEOLOGICAL SURVEY
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SUMMARY

The East Antarctic Seismic Traverse (EAST93) was a geophysical traverse designed to image the bedrock under the East Antarctic ice cap. The traverse started 10 km west of the Taylor Dome drill site and 25 km west of the exposed bedrock of the Transantarctic Mountains at Lashly Mt. and ended 323 km west of the drill site over the Wilkes subglacial basin (Fig. 1). The traverse was located subparallel to latitude 78° S starting 30-50 km north of the Victoria Land Traverse (1958-1959). It was carried out jointly by the U.S. Geological Survey and Stanford University, U.S.A., together with the Institute of Geological and Nuclear Sciences, and Victoria University, New Zealand, during December 1993 and January 1994. The geophysical traverse included 236 km of multichannel seismic reflection data at 150 m shot intervals, 312.5 km of gravity data collected at intervals of 2.1 km, 312.5 km of magnetic data (total field intensity) collected at average intervals of 0.5 km, and 205 km of ground penetrating radar at intervals of 77 m. Relative locations and elevations of the entire traverse were measured at intervals of 150 m by traditional surveying methods, and tied to three absolute locations measured by the Global Positioning System (GPS).

EAST93 is the first large-scale geophysical traverse on the polar plateau to our knowledge since the early 1960s. As such, the experiment presented several logistical challenges: (1) how to collect regional seismic profiles during the short Antarctic summer; (2) how to keep the scientific instruments running with minimal protection in harsh conditions; and (3) how to combine daily moves of camp with full days of work. The scientific and logistical aspects of the project proceeded, in general, according to plan despite the harsh conditions and our lack of previous experience on the polar plateau. Two unanticipated problems affected the progress of the work: the strong wind which slowed seismic acquisition, and the break-down of one of the large traverse vehicles. The major operational lessons of this project are. (1) Primacord laid close to the surface is not an adequate seismic source for imaging under the thick East Antarctic ice sheet, despite positive prior tests on the Ross Ice Shelf. (2) It is necessary to reduce the 6-7 hours spent daily on camp move and other chores by integrating the living quarters into the working teams, and by improving vehicle warming methods and generator housing.

The following report details the operational and logistical aspects of the work, the weather and ground conditions, the technical aspects of acquisition of geophysical data, and lessons and recommendations for future geophysical traverses.

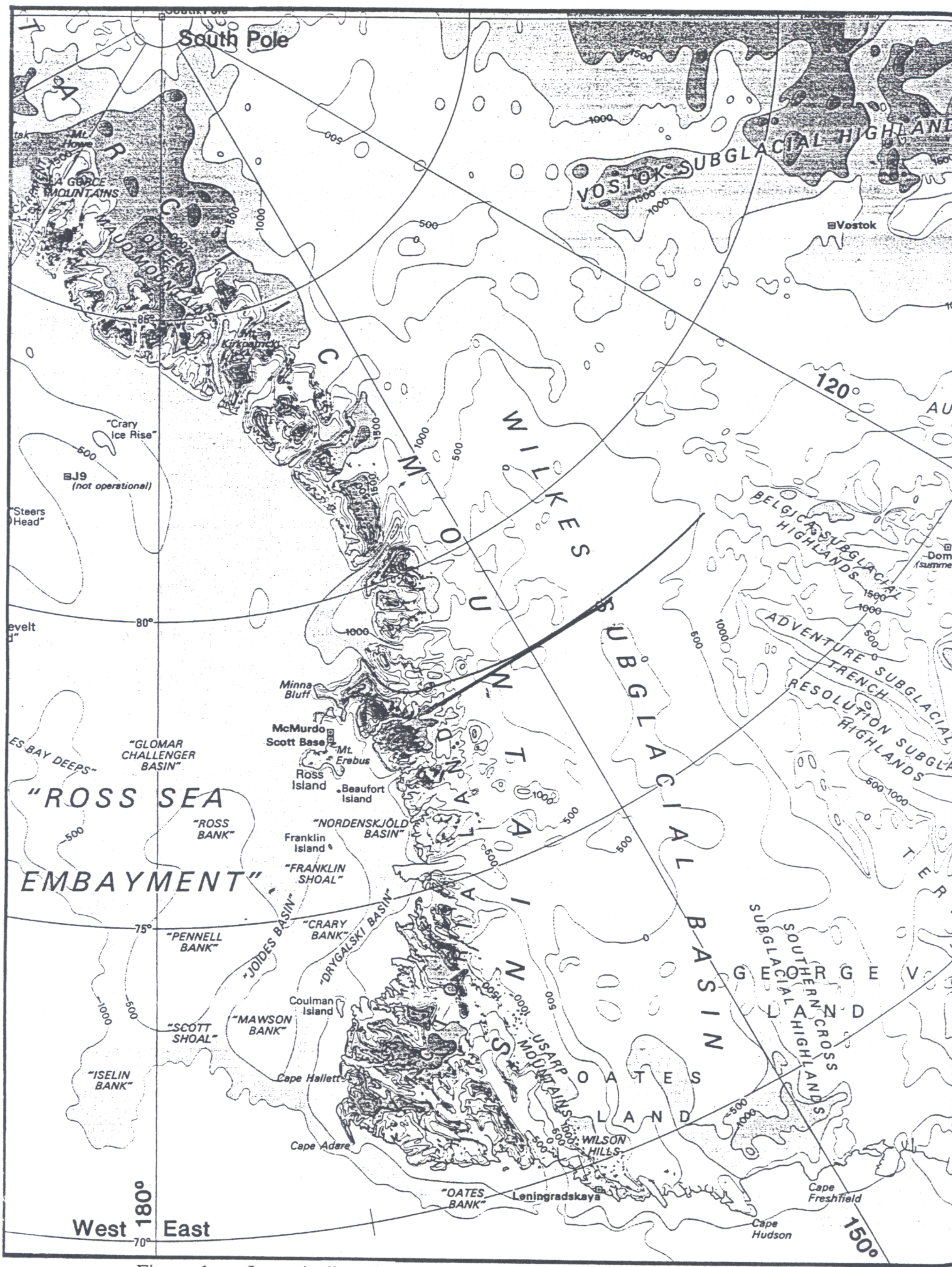


Figure 1. Isostatically-adjusted bedrock elevation map of East Antarctica next to the Transantarctic Mountains (from Drewry, 1983). The location of the traverse is shown by the heavy line, and the location of the 1958/59 traverse is shown by the light line.

SCIENTIFIC OBJECTIVES

By imaging the bedrock under the East Antarctic ice sheet between the Transantarctic mountains and the Wilkes subglacial basin, we hoped the experiment would enable us

(1) To provide quantitative constraints for modeling the uplift of the Transantarctic Mountains and the subsidence of the Wilkes Basin as a flexed lithospheric plate with a free-edge at the boundary with West Antarctica (Stern and ten Brink, 1989).

(2) To map the extent of the Ferrar dolerite sills and basalts inland from the mountains in order to discern whether they originated from an active mantle plume or from rifting and passive upwelling (Elliot, 1991).

(3) To analyze the seismic stratigraphy of the Wilkes Basin sediments to help resolve the debate about the climatic conditions and the size of the ice sheet in the Cenozoic, in particular, whether parts of East Antarctica were deglaciated for much of the Late Cenozoic (Webb, 1991).

PREVIOUS WORK IN THE AREA

Only one traverse was carried out in this area prior to the EAST93 experiment: the Victoria Land Traverse led by A.P. Crary in 1958-1959 (Crary, 1963) (Fig. 1). Crary's traverse collected gravity and seismic reflection and refraction data, but the quality of the data were limited by the technology available at the time. Ice coring and related glaciological studies were carried out at Taylor Dome between 1991-1994, located 10 km east of the start of the line (Fig. 2) (Grootes and Steig, 1992; Morse and Waddington, 1992). Rock outcrops at Beacon Heights, located 45 km east of the start of the line, were mapped by McElroy and Rose (1987), and laboratory measurements of velocity and density of rocks from the Beacon Group in this area of the Transantarctic Mountains were made by Barrett and Froggatt (1978). A regional airborne radio-echo sounding survey grid, centered at about km 0 (Fig. 3), was carried out in January 1975 by the joint National Science Foundation-Scott Polar Research Institute-Technical University of Denmark (NSF-SPRI-TUD) program (Drewry, 1982). Several flight tracks carried out in 1971-72 as part of the continent-wide airborne radio-echo sounding survey by the NSF-SPRI-TUD program (Drewry, 1983) crossed the traverse area (Fig. 3). Ice thickness and surface elevation data, digitized by the British Antarctic Survey (BAS) personnel (David Vaughan, pers. comm., 1993) from film records collected by these two projects, were used to construct the base map for our experiment (Fig. 3). Estimated errors in these airborne surveys were < 5 km in navigation, 1% in ice velocity, 26 m in air and 14 m in ice in signal resolution, and 50-150 m in flight height (Drewry et al., 1982).

FIELD PERSONNEL

<u>United States</u>

Uri ten Brink	(USGS Woods Hole) - Co-leader
Rafael Katzman	(MIT/WHOI Joint program in Oceanography) - Student
Yizhaq Makovsky	(Stanford University) - Student

<u>New Zealand</u>

Stephen Bannister	(Inst. Geological and Nuclear Sciences) - Co-leader and shooter
Mike Collins	(New Zealand Antarctic Program) - Mechanic
Ron Hackney	(Victoria University, Wellington) - Student
Jan de Vries	(New Zealand Antarctic Program) - Search And Rescue (SAR)

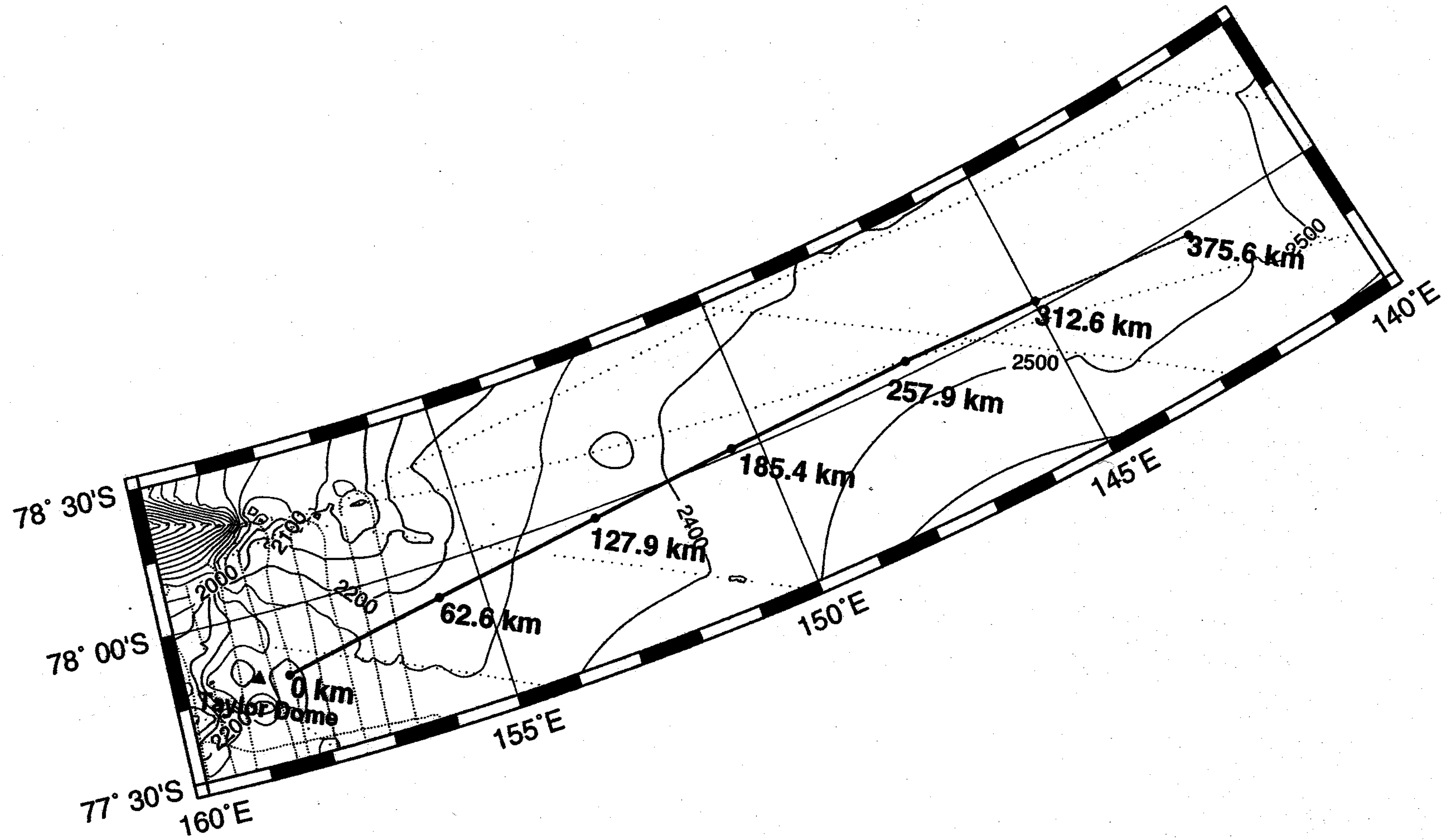


Figure 2. Surface elevation map of East Antarctica in the vicinity of the traverse (100 m Contour interval). Map was contoured from digitized values of elevation collected by the NSF/SPRI/TUD airborne radio echo-sounding surveys in 1971-72 and 1975 (D. Vaughan, SPRI, written comm., 1993). Heavy line - location of traverse. Dotted lines - locations of flight lines of the 1971-72 and 1975 surveys. Heavy dots

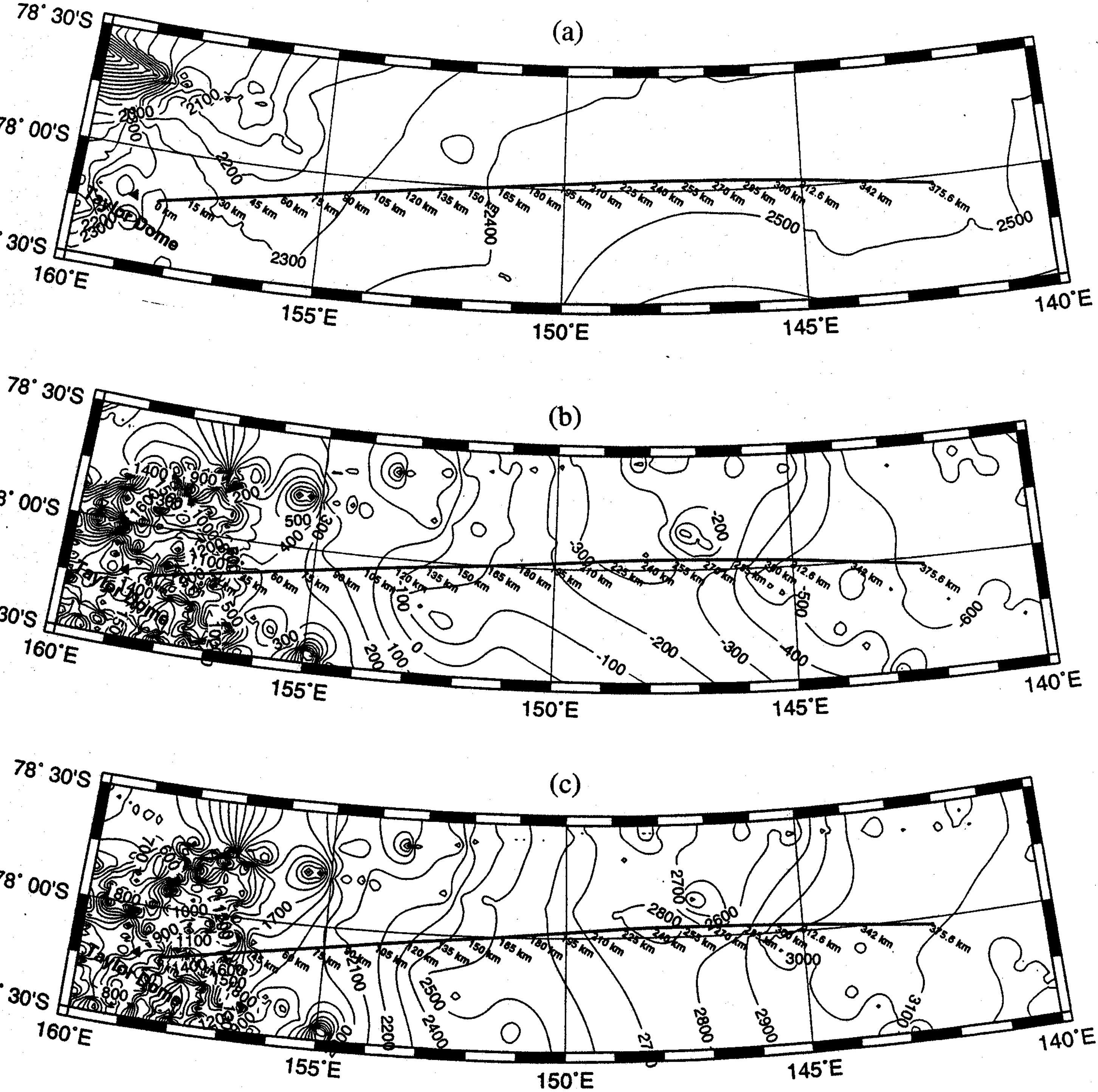


Figure 3. (a) Surface elevation, (b) bedrock elevation, and (c) ice thickness maps of East Antarctica in the vicinity of the traverse. Maps were contoured from digitized values of elevation and ice thickness collected by the NSF/SPRI/TUD airborne radio echo-sounding surveys in 1971-72 and 1975 (D. Vaughan, SPRI, written comm., 1993). Heavy line - location of traverse.

David King	(Inst. Geological and Nuclear Sciences) - Electronic technician
Bill King	(New Zealand Antarctic Program) - SAR person
John West	(Dept. Surveying & Land Information) - Surveyor

TIME TABLE AND LOG

The party spent a total of 54 days in the field, with some personnel arriving in the field 2 days earlier and leaving a day later than the rest of the party. Of these 54 days, 20 days were spent shooting seismics, 17 days were lost to bad weather, 4 days were lost to dealing with the broken large traverse vehicle (Tucker 069) and consequently the need to rearrange the work, 3 days were lost to emptying supply caches and getting air supply, 5 days were spent in organizing the work and overcoming technical problems, and 2 days were spent in preparation for pullout (including a runway for C-130).

22 Nov. -2 Dec: Twin-Otter support for reconnaissance of traverse, fuel and food dispersal in depots at km 0 (Alpha), km 63 (Delta), km 128 (Bravo), km 185 (Echo) , km 258 (Charlie), and km 313 (Foxtrot) (Fig. 2), pickup of parachutes used to drop explosives, and GPS survey of reference points at km 0, 128, and 258.

29-30 Nov: RNZAF C-130 air drops of explosives at km 0, 128, and 258.

1 Dec: Put-in of survey party at Taylor Dome.

3-6 Dec: Put-in of main party and its equipment at Taylor Dome.

8-10 Dec: Main party moves to km 0 (Alpha), repairs damage to snow streamer, refuels from Taylor Dome.

11 Dec: Seismic work begins, fuel supply and generator replacement by Twin-Otter.

15 Dec: Work terminates at 3 p.m. due to high winds.

16 Dec: No work due to high winds.

18 Dec: No work due to a snow storm.

22-23 Dec: 2 people travel 165 km overland to bring more explosives from Alpha and replacement generators and transformer from Taylor Dome. They measure a continuous radar profile.

23-26 Dec: No work due to high winds.

27 Dec: High winds, advance without shooting seismics between km 75-90.

29-31 Dec: No work due to high winds.

4 Jan: Walk-away shots, Makovsky develops tooth abscess and needs to be evacuated.

6 Jan: High winds, advance without shooting seismics between km 162-185.

7 Jan: Survey team finishes flagging to km 375.

8 Jan: Slow movement due to bad sastrugi (parallel ridges of wind-blown hard snow). Shot size and length increased by 50%.

9 Jan: Survey team joins main team at km 200.

10 Jan: Skidoo AL3 breaks front shaft and is towed on a sled until the end of the traverse.

12 Jan: Twin-Otter makes a difficult landing due to sastrugi. It evacuates surveyor, electronic technician, and Makovsky, and brings replacement computer hard drive.

13 Jan: Morning whiteout prevents advance through sastrugi field. Work commences in afternoon, but Tucker 069 (which tows the camp) develops transmission problem.

14 Jan: Runway prepared for Twin-Otter to bring replacement for transmission.

15 Jan: No work due to whiteout.

16 Jan: Main camp splits. Tucker 069 and mechanic left behind, science party continues.

17-19 Jan: No work due to bad storm.

20 Jan: Digging out and work. Twin-Otter with mechanic and Makovsky arrives at Tucker 069 location to replace transmission. Replaced transmission fails.

21 Jan: Twin-Otter arrives at Tucker 069 location with a mechanic and another transmission. Science party retrieves explosives, fuel and food from depot Charlie.

22-23 Jan: Tucker 069 and science party meet and move toward Foxtrot, but forced to stop at km 270 after complete transmission failure of Tucker 069.

24-25 Jan: Gravity and magnetics measured out to km 312.6. Supplies at depot Foxtrot retrograded to km 270. Twin-Otter arrives with snow groomer and operator to prepare runway for LC-130.

26 Jan: Last day of seismic work.

28-29 Jan: Pull-out of equipment and personnel by 7 LC-130 flights from km 270.

INSTRUMENTATION

Location And Surveying

USGS/NMD determined GPS positions at the fuel depots near km 0 (Alpha), 127.95 (Bravo) and 257.86 (Charlie) (Fig. 2). GPS surveys were conducted on November 29 and December 1, 1993. Geoid separations were obtained from OSU91A Geoid Interpolation Program, The Ohio State University, department of Geodetic Science and Surveying. Horizontal accuracy is in the 1-meter range.

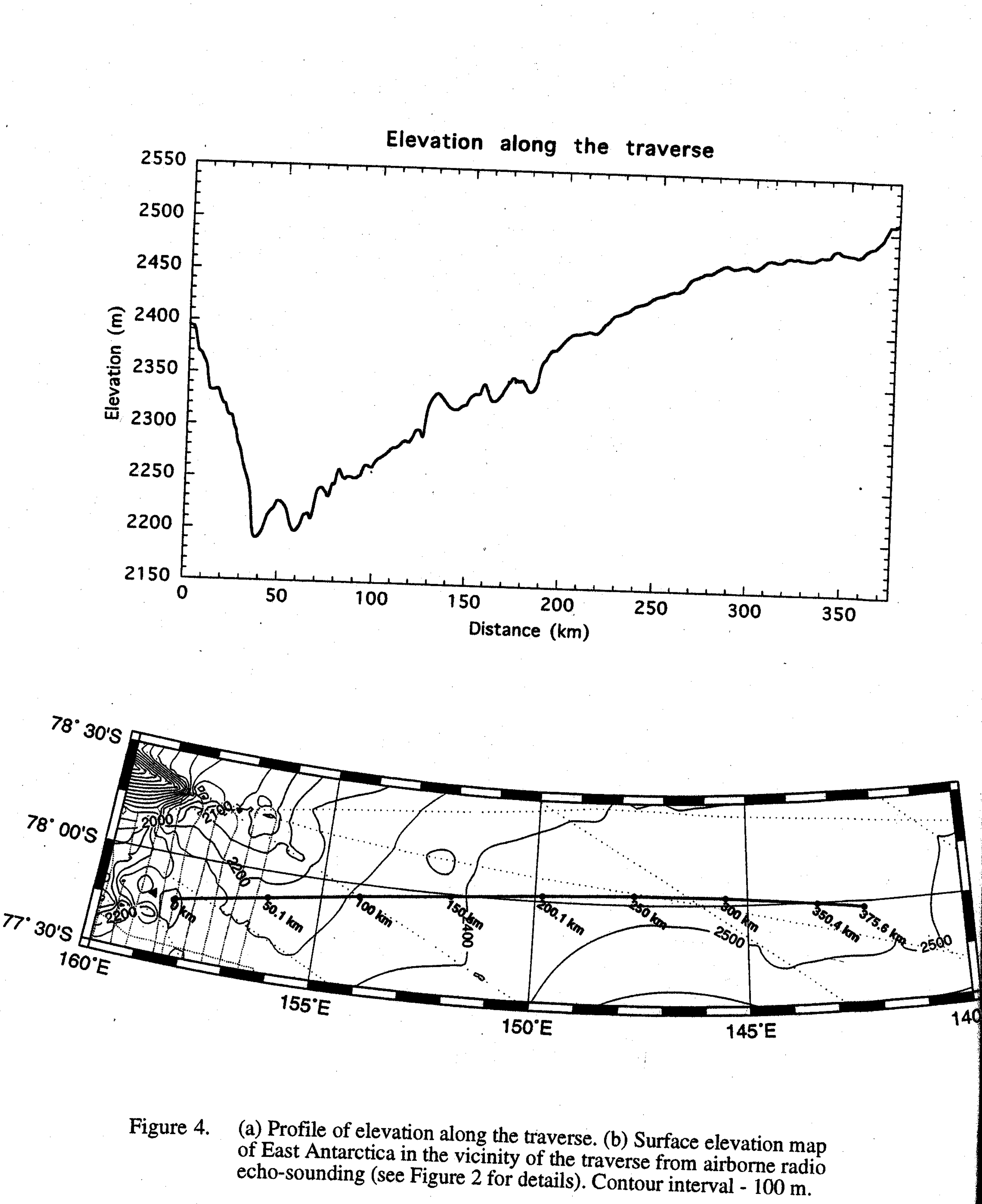


Figure 4. (a) Profile of elevation along the traverse. (b) Surface elevation map of East Antarctica in the vicinity of the traverse from airborne radio echo-sounding (see Figure 2 for details). Contour interval - 100 m.

In addition to these measurements, relative elevation measurements were carried out by the DOSLI surveyor, John West, in the advance survey group using conventional land surveying techniques. The location of each measured position along the traverse starting from km 0 is given in Appendix 1 with elevations calculated using the Alpha GPS site as the absolute elevation and accepting a geoidal separation of 50.1m there (see Table below). (The distance azimuth from Alpha to 'km 0' were 937.5 m and 229.82°.) The (relative) ground measurement survey agreed with the GPS values at Bravo and Charlie within to 3 meters, about the order of error that might be expected using the GPS in this manner.

GPS POINTS:

Site	WGS 84 Coordinates	Elliptical Height (m)	Geoid Separation (m)	Ortho. Height (m)	Surveyed Height (m)
Alpha	77° 46' 42.29"S 158° 20' 30.89"E	2345.5	-50.1	2395.6	2395.6 (Accepted as origin)
Alpha AZ	77° 47' 14.01"S	2342.7	-50.1	2392.8	
	158° 21' 21.31"E				
Bravo	77° 57' 08.15"S	2270.6	-53.7	2324.3	2324.1
	152° 55' 04.87"E				
Charlie	78° 05' 23.16"S	2388.9	-54.1	2443.0	2440.9
	147° 20' 28.87"E				

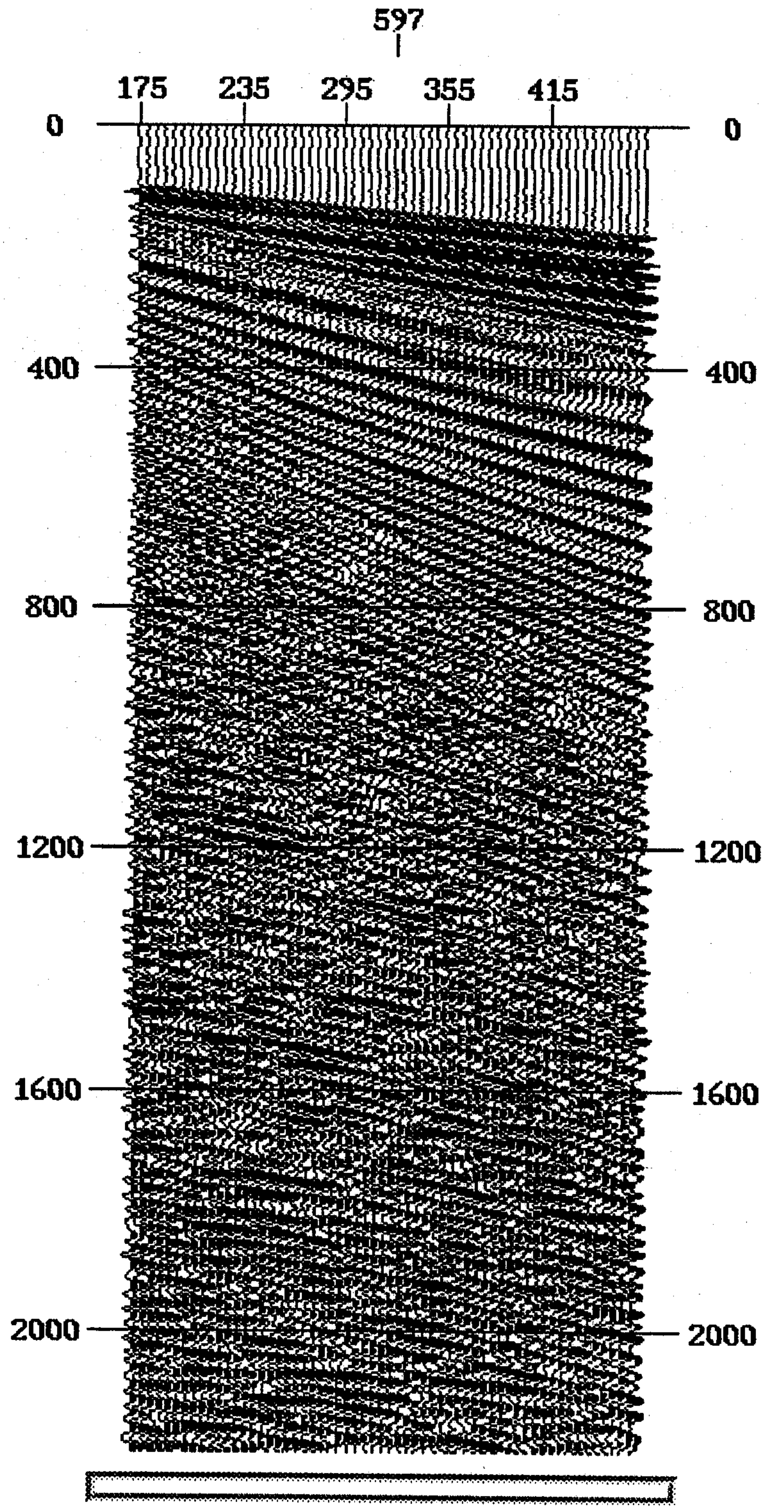
Figure 4a shows a profile of the elevation measured along the traverse and Fig. 4b shows the location of the traverse, with approximate elevation contours from the 1970s airborne data. Appendix 1 lists the locations of surveyed positions, and their elevations.

Additionally, barometer readings were taken during supply flights to 6 points along the traverse and at intervals of 2.1 km along the traverse, but these were not used to calculate elevation.

Seismics

The shot parameters were as follows:
Type of source - Geoflex 40 detonating cord (primacord) with 40 g/m dynamite (200 grain).
Manufacturer - ICI Australia.
Shot size - 1.6 kg (40 m long cord) between km 0-162.
2.4 kg (60 m long cord) was used between km 185-270.
Shot depth - 16.5 cm (6.5').
Shot interval - 150 m.
Shot-receiver offset for near trace - 175 m between km 0-162.
185 m between km 185-270.
Survey geometry -Marine, except for walk-away calibration shots to a stationary streamer (maximum offset of 3.2 km) at km 148 and 270.

Figure 5. Example of a seismic field record from a seismic shot at km 74.7, after application of a 500 ms automatic gain control. The vertical axis represents two-way travel time, in ms. The horizontal axis is shot-receiver offset, in m.



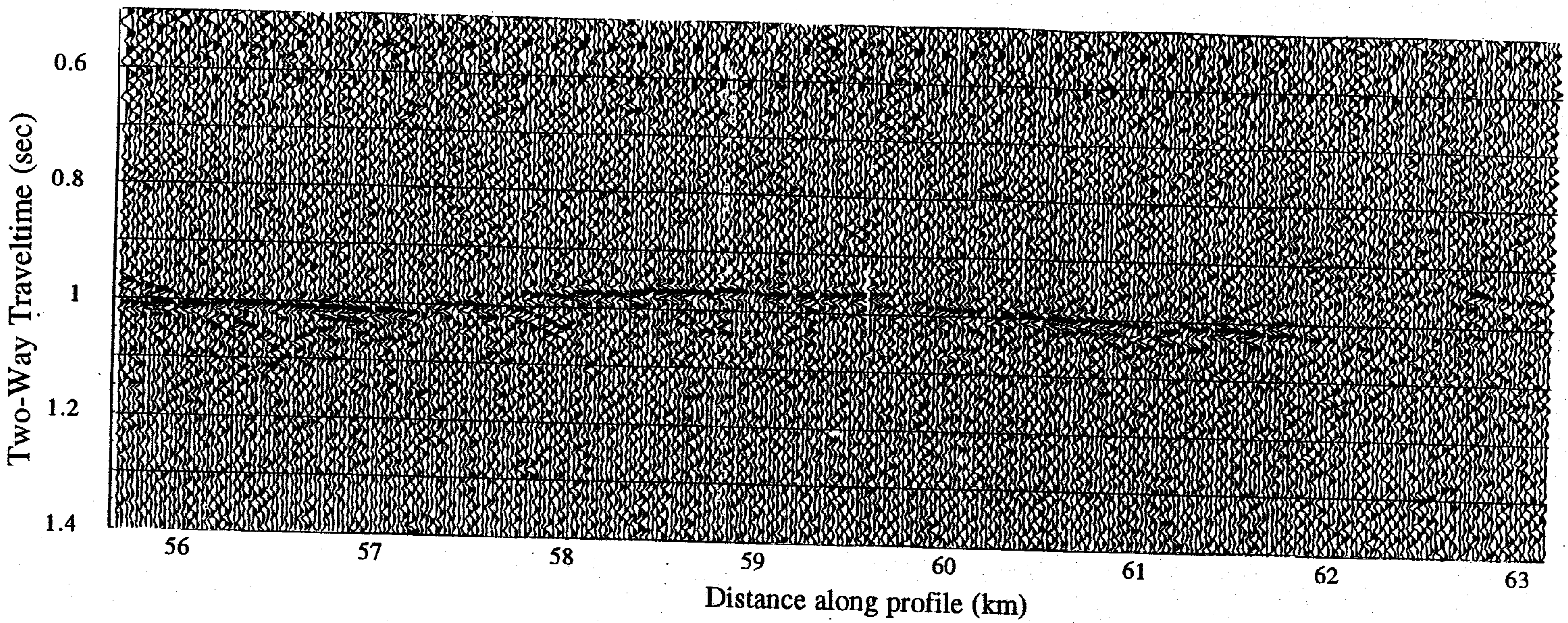


Figure 6. A portion of the stacked and binned multichannel seismic data along the traverse.

Seismic data were recorded using a Geometrics Strataview R-60, a 486 PC-based portable computer, with 18 bit A/D converter, 500 MByte hard drive, Colorado Jumbo tape drive and a built-in plotter. Sampling rate was 1 msec and record length was 4 sec. The unit demultiplexed as it recorded and had several display functions. Processing for field quality control was performed using the Eavesdropper™ software developed by the Geological Survey of Kansas.

The seismic receiving system consisted of a 300-m-long snow streamer made by Norsk-Hydro of Norway. The streamer is a towed Kevlar seismic cable with 60 take-outs (channels) at 5 m intervals. Each take-out is a cable with 4 single-axis gimbaled geophones per channel, ~3.1 m apart.

Fig 5 shows a field record of seismic data collected during the experiment, and Fig. 6 shows a portion of the stacked data. The location of shot points is listed in Appendix 1.

Gravity
Gravity observations were made every 2.1 km, using a LaCoste-Romberg gravimeter G-179. The gravimeter was continuously attached to a battery that supplied power to an internal heater, which maintained the gravimeter at a constant temperature. In addition, the gravimeter was cased in a Perspex box with holes for the dials, and this box and the battery were kept in a wooden box. The gravimeter was kept inside a vehicle at all times and was brought outside only for the measurements. The gravimeter values were tied to Scott Base gravity station before the experiment. Instrument drift was calculated by successive measurements over several days at the same location (km 269.7) The observed gravity is plotted in Fig. 7 and listed in Appendix 2.

Magnetics
Magnetic readings were carried out using two Geometrics G-856 magnetometers. One magnetometer was used as the roving station at intervals of 300-450 m and the second one as a temporary base station at the daily base camp to record the diurnal variations in the magnetic field. The base station magnetic sensor and magnetometer required adequate insulation to operate properly at these temperatures. The sensor was wrapped with insulated material and a hand warmer was wedged between the sensor and the insulation. The magnetometer was enclosed in a food box containing a hot water bottle. The raw magnetometer readings observed by the 'roving' station are plotted in Fig.8 and listed in Appendix 1 together with their day of measurement.

Ground penetrating radar
Radar measurements were made at intervals of 77 m from Taylor Dome to km 195.5, a total of 205 km. Data were collected while the radar system was moving using a wheel to measure the distance and an electroinc trigger to start acquisition. The system included low frequency receiving and transmitting antennae (1.25 MHz) with resistivity constants of 400 Ohm. The radar transmitter supplied a voltage pulse of 750 V. The data were received and sampled using a digital oscilloscope (Fluke 97 Scopemeter) which stacked 256 readings to form one trace. Data were sampled for 40 microseconds (μsec) at 0.08 μsec per sample and recorded on a BCC Avanti 486 portable computer. The data were converted into SEG-Y format which allowed us to use standard seismic processing tools for display and analysis. Detailed description of the acquisition system and data reduction are given in Appendix 3.

The trace in Figure 9A displays the characteristic waveform of the radar signal. The first arriving air-wave is clipped to allow good resolution of the reflected signal. Reflections from within the ice around 7-8 μsec are difficult to discern on this single trace. The signal arriving around 10 μsec is an artifact we can not explain. The ice-rock interface reflection can be clearly seen at 13 μsec two-way-time translating to a depth of about 1 km. We plan

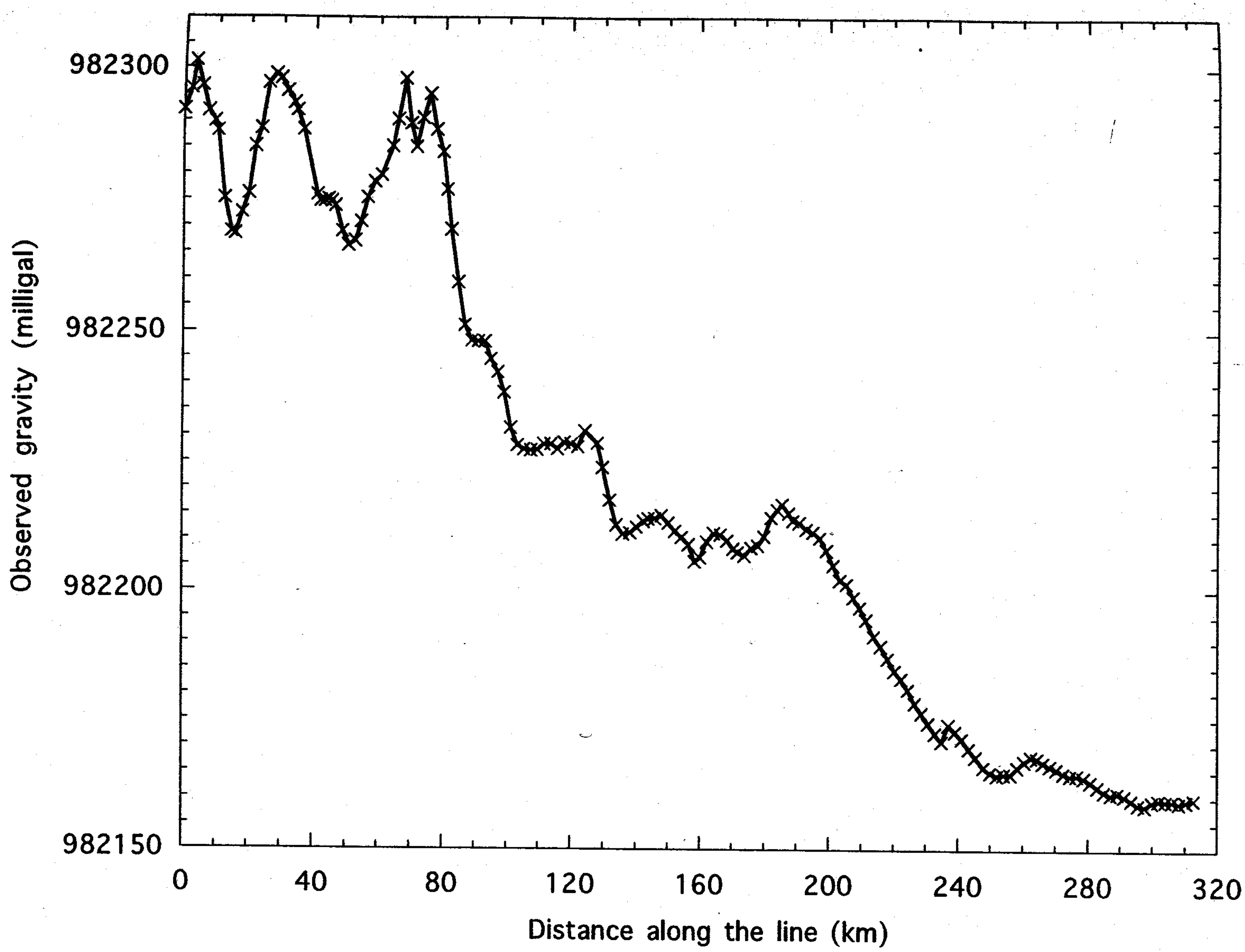


Figure 7. Observed gravity (in milligal) along the traverse.

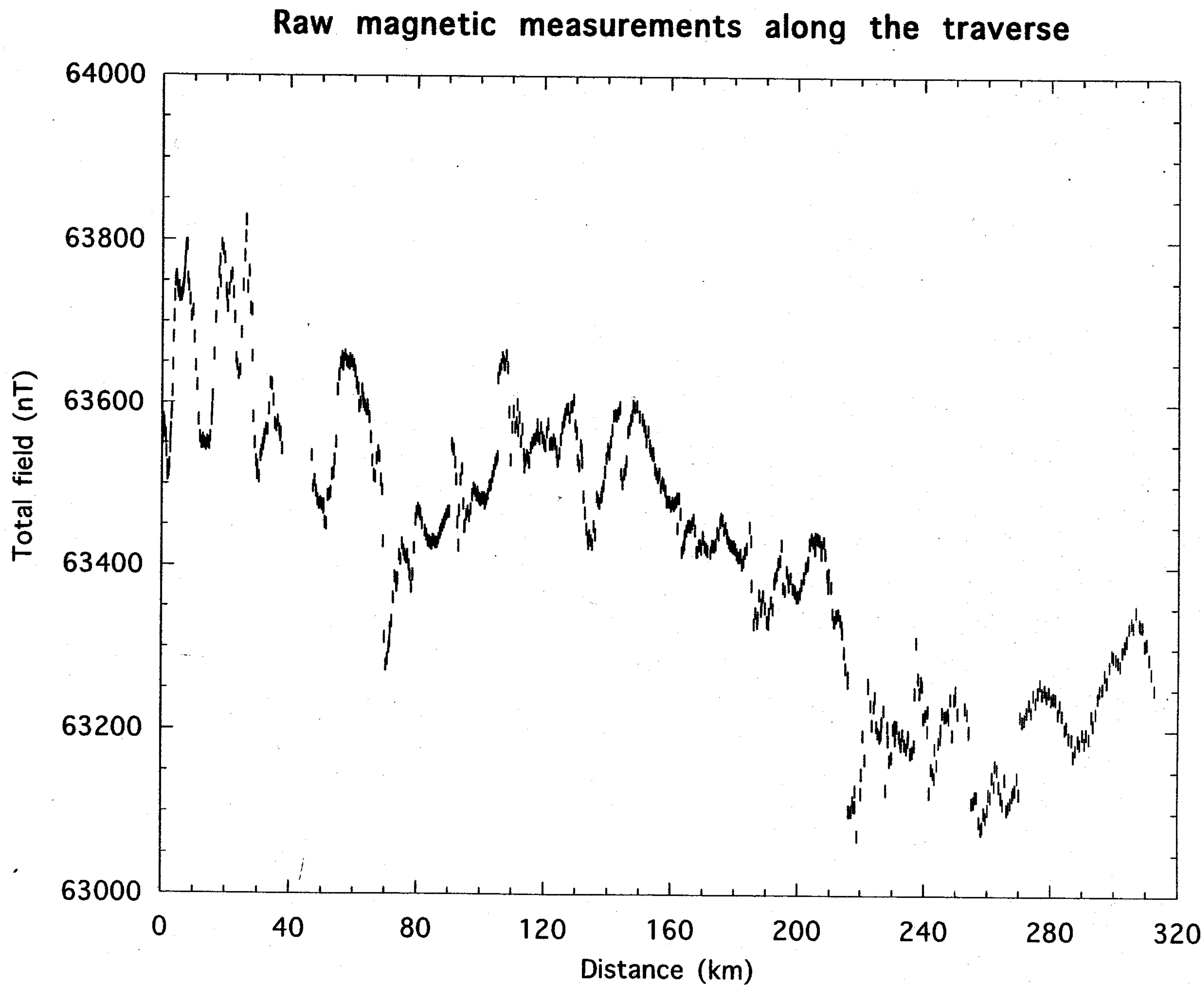


Figure 8. Raw magnetic measurements (in nT) along the traverse line

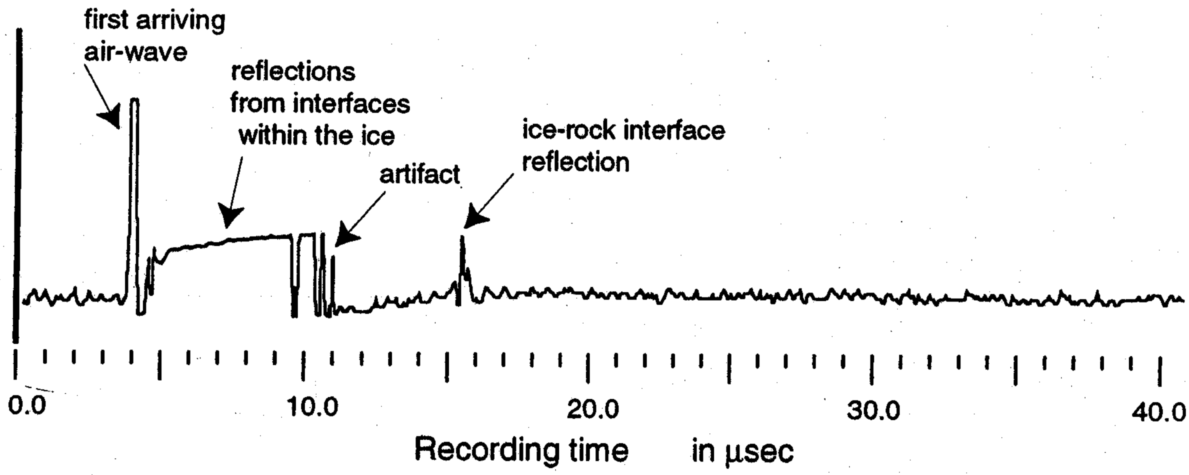


Figure 9a. An example of a typical trace (no processing applied). This trace was recorded in surface location km 67.4 with 4 µsec pre-trigger length, 20 mV/div gain and 0.08 µsec sample interval using the four-stage transistor avalanche source and the Fluke 97 based recorder.

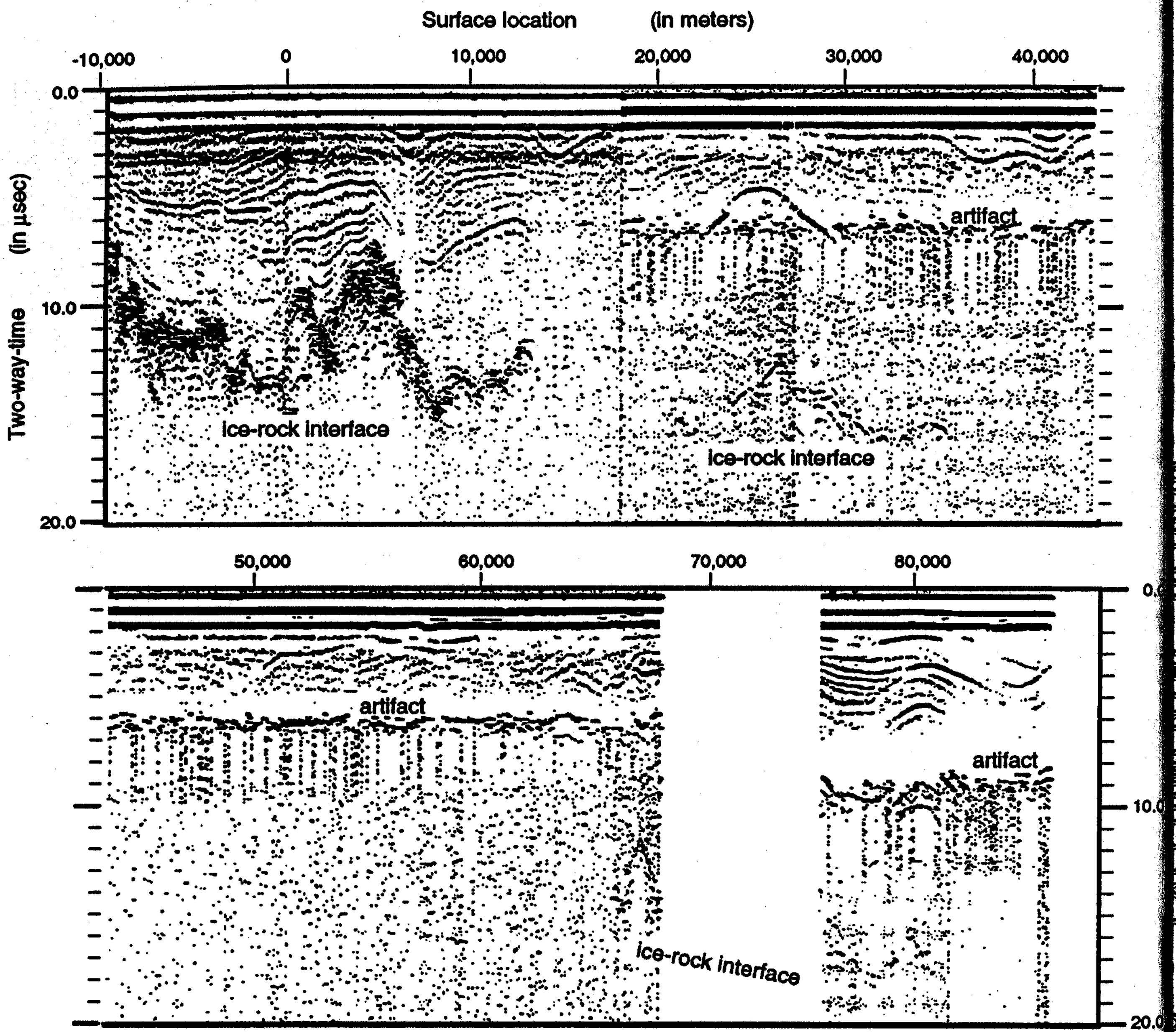


Figure 9b. 96 km-long section, acquired from Taylor Dome (surface location km -10), on the upper left, to surface location km 86.1, on the lower right. To produce the section, 8 files were combined, adjacent traces subtracted, variable gain applied and traces plotted by surface location. The gap in the image occurs where no data were acquired.

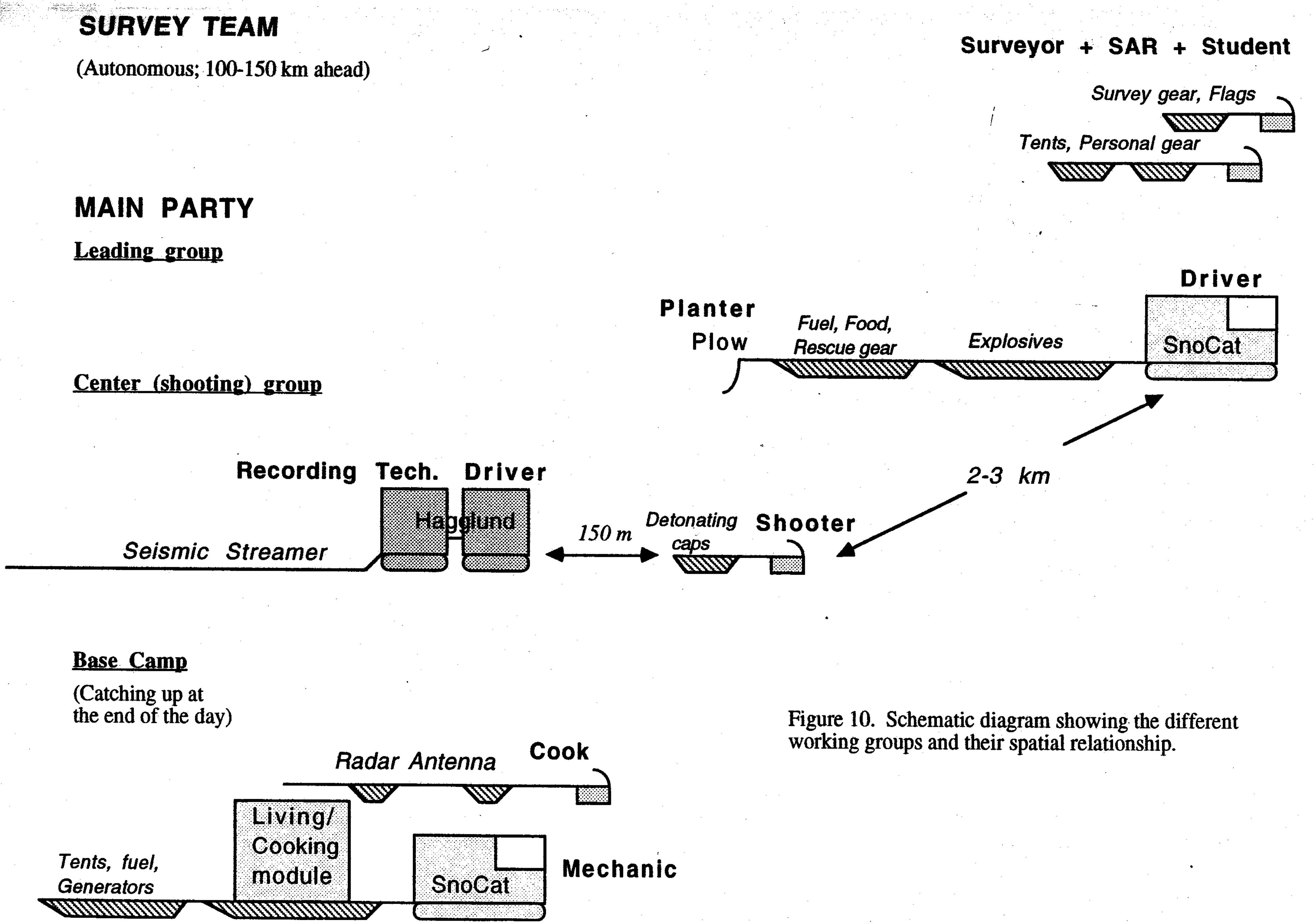


Figure 10. Schematic diagram showing the different working groups and their spatial relationship.

to subtract adjacent traces from each other in each data-file to cancel the air wave and most of the artifacts, and to enhance the reflected signals.

The image in Figure 9B displays a 96 km long section, acquired across the flank of the Transantarctic mountains to the edge of Wilkes basin. A strong reflection from the ice-rock interface can be seen around 7-8 μsec on the left of the image. The rough shape of this reflector describes a rough subglacial topography similar to the exposed topography of the Transantarctic mountains. This reflector becomes discontinuous and weak as the travel time increases to about 17 μsec, or about 1400 m deep, and disappears completely on the right of the image.

The features seen between the surface and the ice-rock interface are reflections of interfaces within the ice. These can be different layers of ice deposited on the ice sheet, layer of dust etc. These reflectors seem to wrap around the topographic features at the base of the ice in complex flow patterns. The horizontal bands of signal around 10 μsec are the artifacts pointed out in Figure 9A.

METHODOLOGY

The field work was conducted in the following way (Fig. 10):

An advance survey group which included a professional surveyor with an Electronic Distance Meter (EDM) (J. West), a Search And Rescue (SAR) person (B. King), and a student (R. Katzman). The advance group moved autonomously 100-150 km ahead of the main party on 2 skidoos with Nansen/Tamworth sleds. The survey party was put in the field 6 days before the main party. It advanced, on average, 15 km a day. It surveyed and planted flags every 150 m. It drew food and fuel from caches.

The main party consisted of 3 separate working groups, which converged nightly:

1. The leading group laid 40-60 m long pieces of detonating cord below the surface using a plow at 150 m intervals, and carried out magnetic and gravity measurements. The group included 2 people: The Tucker driver, who was also a qualified SAR person (J. de Vries), checked for crevasses, measured the magnetic field every 450-600 meters, and wind speed, temperature and barometric pressure every 2.1 km. The second person (U. ten Brink/R. Hackney) on foot behind the snow plow held the end of the detonating cord while the Tucker pulled the plow forward, stomped on the trench to pack the snow over the detonating cord, and cut the end of the detonating cord at the proper length. The second person also measured gravity every 2.1 km. The leading Tucker stopped and idled its engine before each shot detonation, in order to reduce the ambient noise on the seismic records.

The leading group had the following equipment: A Tucker Snocat which towed (i) an Anare sled (a midsize sled-1770 lb., 12 x 6 ft., 2-3 ton carrying capacity) loaded with explosives and 3 fuel drums, (ii) a Maudheim sled loaded with heavy rescue gear (400 lb.), spare streamer sections, spare generators, 4 60 liter drums and miscellaneous equipment as necessary, and (iii) a snow plow.

2. The center (shooting) group consisted of a large tracked vehicle (Hagglund) towing the 60 channel, 300 m long snow streamer, and an Alpine-II Skidoo towing a box sled ("Sleepy sledge") loaded with detonators. The seismic recording unit was housed in the back of the Hagglund. It included 3 people : the shooter (S. Bannister / U. ten Brink) on a skidoo about 150m in front of the Hagglund, the driver of the Hagglund, and the recording

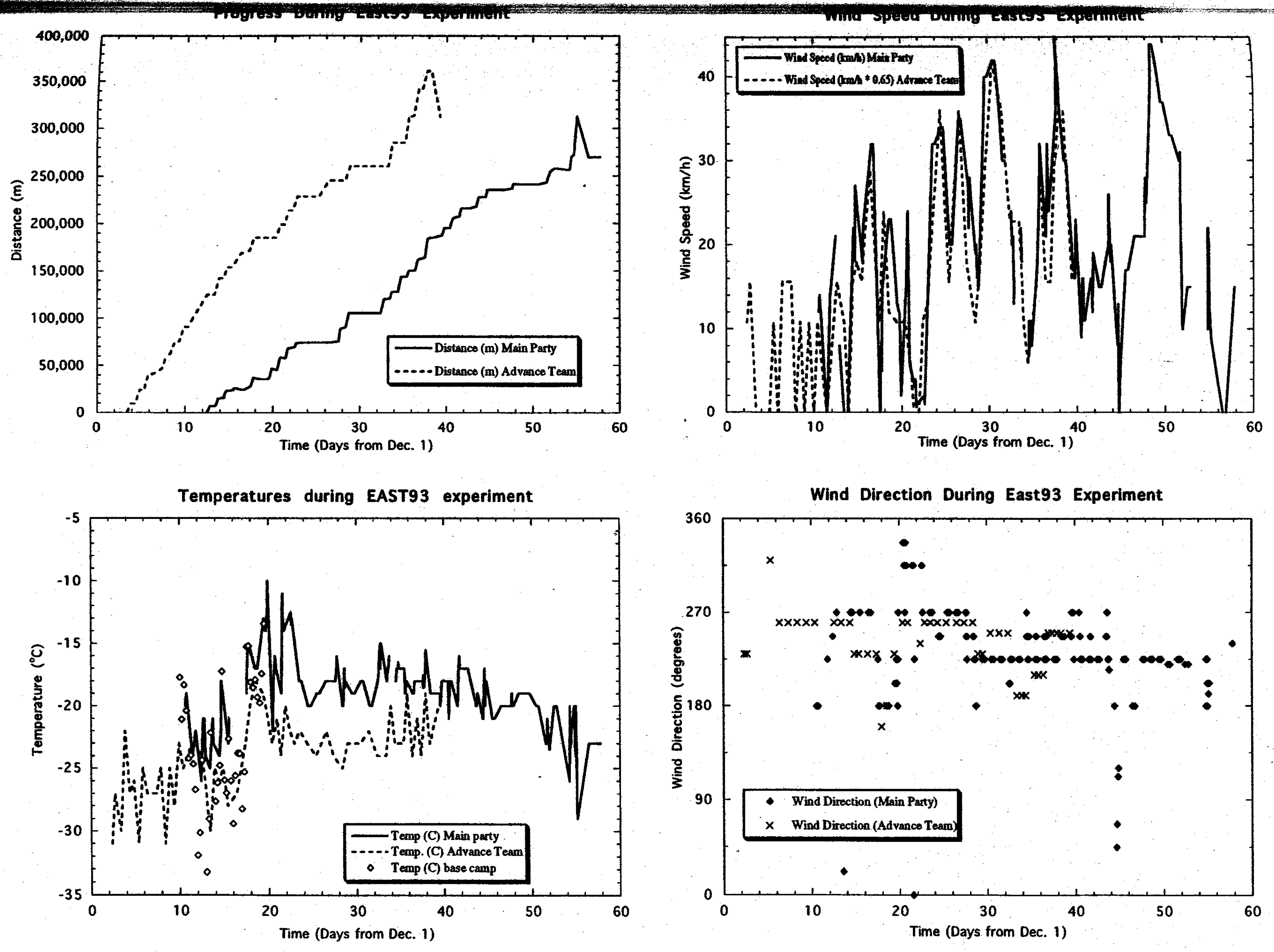


Figure 11. Wind speed, surface temperature, and wind direction plotted as a function of time for the main party and the advance party. Upper left plot shows location of both parties along the traverse line as a function of time.

technician in the back of the Hagglund. At each shot location the shooter connected a detonator to the primacord (laid by the leading group), and the shot wire to the detonator. The Hagglund driver (R. Hackney / S. Bannister) connected the end of a 180 m long electric wire trailing behind the shooter into the Hagglund, turned the flag nearest to him upside down (to reduce wind noise during recording), idled the engine for 2 minutes, and then shut the engine off. The driver was also responsible for alerting the leading and camp groups of an impeding shot and giving the 'all clear' signal. The recording technician (D. King / R. Katzman) in the back of the Hagglund carried out the seismic recording and the quality control. The center (shooting) group followed 2-3 km behind the leading group by starting work 1-1.5 hours after the leading group. The distance between the groups was maintained to minimize the effect of Tucker engine noise on the seismic records.

3. This camp group included a mechanic (M. Collins) and a cook (Y. Makovsky), who also took care of the radar measurements. The camp group was also responsible for setting up magnetic and barometric base stations, the data from which was later compared to the measurements from the roving magnetometer station. Finally, the camp skidoo driver (Y. Makovsky) was responsible for turning the flags back to right side up. The camp group started moving about 2-3 hours before the end of the shooting day. Earlier movement would interfer with the shooting. radar data were recorded continuously during this movement.

The base camp had the following equipment: (i) a Tucker Snocat towing the camp (an Anare sled with a living module (Wannagan), and a 1-ton sled with 6 fuel drums, Herman Nelson, 2 generators, tents, and miscellaneous camp equipment), and (ii) an Alpine II skidoo towing the radar equipment (radar antennae and Nansen and banana sleds on which separate receiving and transmitting equipment were emplaced).

ENVIRONMENTAL CONDITIONS

The elevation above mean sea level was 2395 m at km 0 (10 km west of McMurdo Dome drill site), decreasing to 2190 m at km 37.8 and increasing gradually to 2470 m at km 312.6 with undulations of up 20 m on a 10 km scale (Fig. 4 and Appendix 1).

The snow condition varied from soft to steel-hard, with rapid changes in space and time (Appendix 4). The snow was often hard enough to support human steps and skidoo tracks without breaking through. The majority of the terrain was smooth enough to minimize delays in traveling. Some rough stretches with sastrugi up to 1.5 m were encountered. These stretches obviously slowed our progress. Rough stretches were often seen to correspond with lows in the topography (particularly noticeable from 123.6 - 126.3 km). This effect could be accounted for by the fact that such lows would channel cold air, resulting in regions of higher wind speed and greater potential to form sastrugi. In general, the smoothest terrain was encountered at the start of the line and also at the very end of the line. The sastrugi were consistently in a SW - NE orientation parallel to the wind direction and were prominent between km 122 and 265 (Appendix 4).

Temperatures ranged between -15° C and -33° C, with the warmest period between December 17 and January 15. The maximum temperature registered was -10° C (Appendix 5 and Fig. 11)

Generally, the sky was clear with persistent katabatic wind from the west to southwest at 10-40 km/h (6-22 knots), and snow blowing at wind speeds above 30 km/h (17 knots). The daily maximum wind occurred around 6 p.m. local time. Wind speed may have been positively correlated with good weather in McMurdo sound and was highest between December 15 and January 19. Occasionally, weather fronts from the south passed through,

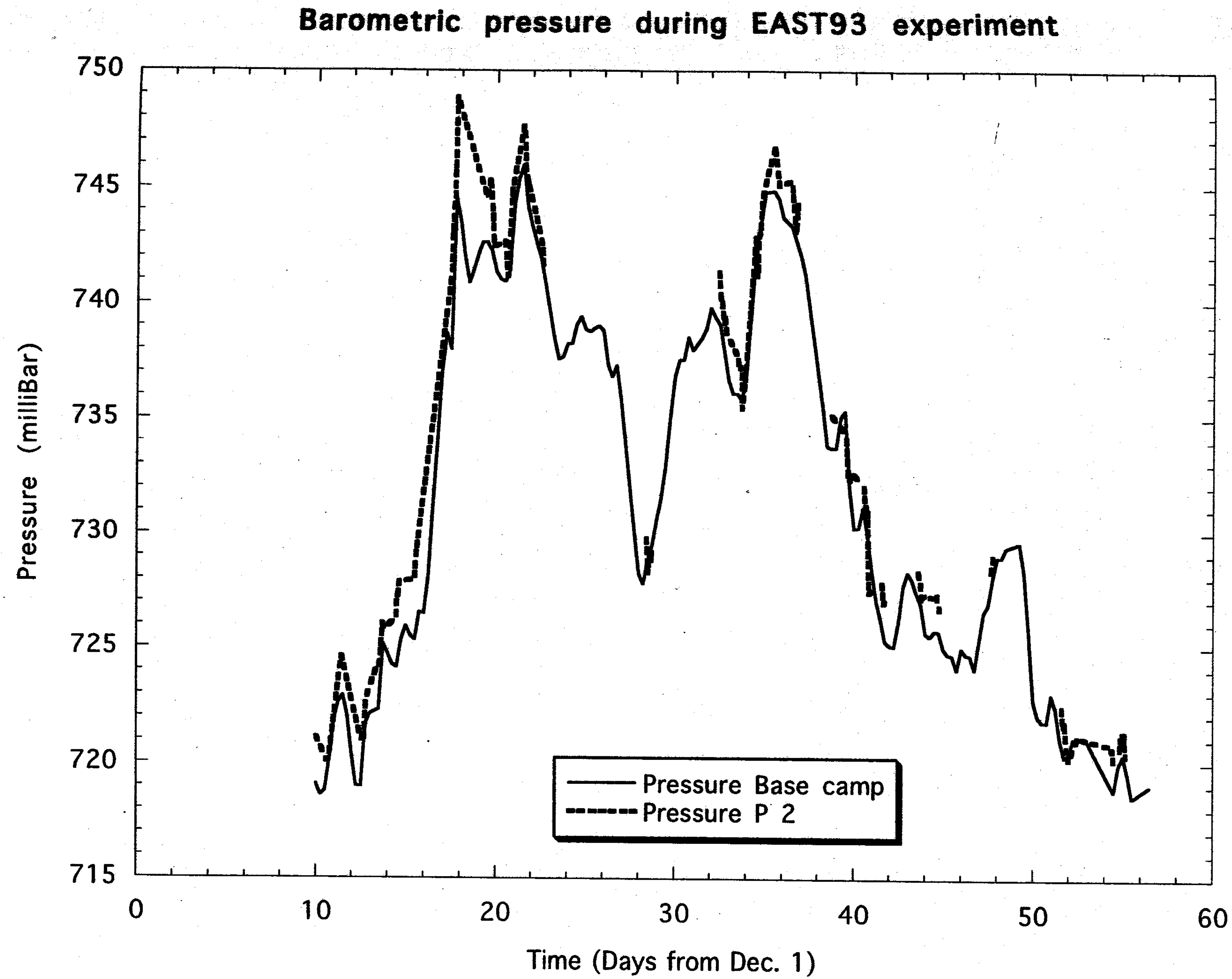


Figure 12. Comparison between barometric pressure (in milliBar) as a function of time measured by the roving station (P2) vs. that measured by the temporary base camp. Base camp measurements were carried out every 5 minutes and were averaged by taking the median over a 6 hour period.

with warmer temperatures, little wind, snow fall, and whiteout conditions. Comparison between the survey group and the main group up to 150 km apart along the line indicated uniform weather conditions along the line (Appendix 6 and Fig. 11).

Figure 11 shows the wind speed, surface temperature and wind direction plotted as a function of time for both the advance party and the leading and camp groups of the main party. Fig. 12 shows the barometric pressure during the experiment measured by the leading group at roving stations every 2.1 km along the traverse and by the base camp at daily camp sites. Three separate measurements by two different barometers were carried out at each roving station. The average values of the three measurements for each instrument (P1 and P2) are given in Appedix 5. Figure A5.1 compares the barometric pressure measured by instrument P1 to the measured elevation along the traverse. Note the pressure drop around km 150 (Day 39) which was unrelated to temperature or elevation. Base camp measurements of pressure and temperature were carried out automatically every 5 minutes. Their median values over 6 hours intervals are given in Appendix 7.

VEHICLES AND MAINTENANCE

Appendix 8 details the report from the NZAP mechanic, Mike Collins, on the mechanical aspects of the traverse.

LESSONS AND RECOMMENDATIONS

Seismic Work

1. Detonating cord as a seismic source: Detonating cord (also known as Primacord) appears to be the only source that could be prepared and laid at a rate comparable to the rate of shooting. From experience in the SERIS experiment (ten Brink et al., 1993), 2-3 drilling crews of 2 each and 2 additional people for shot preparation are needed to achieve a similar acquisition rate with down hole shots. In addition, comparisons between downhole and surface primacord shots carried out during the 1990/91 SERIS experiment indicated that the source signature from the surface primacord shot was superior to that from a downhole source (Melhuish et al.,1993).

The seismic signal returned from subglacial layers was, however, disappointingly low relative to ambient noise and "ground roll". Bottom could be clearly imaged in the first 75 km of the seismic work where the ice is relatively thin (700-1700 m), but could seldom be imaged at depths of 2000-3000 m. It appears that the high near-surface velocity gradient in the ice generates strong turning waves and surface waves at the expense of more deeply-penetrating energy. However, this must only be a partial explanation in light of our positive test results with primacord as a seismic source during the SERIS experiment where the near-surface velocity gradient is equally high. High firn noise following shooting, which was a frequent complaint during the IGY experiments (C. Bentley and J. Behrendt, pers. comm., 1993), did not pose a problem in the frequencies of interest (< 80 Hz).

2. Acquisition rate: The leading group laid 10-12 shots an hour, while also carrying out gravity, magnetic, and weather measurements. The center (shooting) group fired up to 10 shots an hour. Generally, 60-80 shots were fired in a full working day with a maximum of 108 shots in one day. These acquisition rates were anticipated on the basis of our experience at the SERIS experiment (ten Brink et al., 1993) and proved reasonable. There were no major problems related to the seismic work in the field.

3. Seismic acquisition at high wind speeds: Shooting could not be carried out at wind speeds in excess of 30-35 km/h for the following reasons. (a) Wind noise on the streamer

became high. (b) Blowing snow at these wind speeds could potentially shorten the electric circuit and cause premature detonation. (c) Detonating required tying electric wires with exposed fingers, and fingers became unbearably cold due to wind chill (temperatures with wind chill were -50° C to -70° C), (d) The plastic cover of the shooting wires became brittle exposing the copper wires and causing misfires. (e) Regular electric tape used for attaching the detonator and for fixing broken shooting wire, was non-adhesive at these temperatures.

4. Snow plow: The snow plow performed very well. The use of the plow over surface-laid primacord had several advantages: (a) It saved one person (2 people were originally allocated, one at each end of the primacord). (b) A buried primacord produced negligible air wave energy. (c) The explosion of buried primacord left much less visible residue (i.e. pollution) than either a surface-laid primacord, or a downhole explosion (as seen during our 1990/91 SERIS experiment). In fact, the explosion of buried primacord was so clean that it was difficult to spot the exact location of the explosion after 24 hours. Plowing could be performed in almost any weather condition.

5. Snow streamer: The use of the Norwegian snow streamer to receive the seismic data (instead of conventional geophones) considerably reduced the logistical effort and manpower in planting geophones and rolling cables.

6. Modern recording system: The use of the Geometrics Strataview recording system (leased at the last moment) instead of the DFS-V system, proved crucial. Its flexibility and ease of use meant that work could continue even after the departure of the electronic technician on January 12. In addition, its battery power consumption was 1/3 that of the DFS-V and its processing and noise display capabilities allowed us to make operational judgments based on the seismic results.

Effect On Humans

1. Length of work day: The daily shift of camp and the low temperatures meant that working days became very long (16-24 hours). Warming up the vehicles in the mornings and preparation for work took 3 hours from wake-up time. Likewise, setting up camp in the evenings, dinner, downloading and saving data, etc., took additional 3 hours. In addition, shooting started 1-1.5 hours after the leading group started plowing and stopped 1 hour before the base camp caught up with the leading and shooting team. In the beginning of the experiment, the leading group would lay an extra 2 km for the shooting group to detonate at the start of the next day, thus eliminating 1-1.5 hours waiting period for the shooting team. This arrangement was abandoned after several storms completely buried the exposed ends of the primacord. Subsequently, all laid primacord was detonated the same day. No better solution was found for the wasted time connected with the base camp. The camp group could not be sent ahead of the other groups because we could not anticipate our daily progress.

2. Living quarters: It is useful for field parties larger than 4 people to have a meeting room for planning and dividing the daily work. Our living quarters served this purpose in addition to serving as a central kitchen and galley. The Wannagan used in this traverse for living quarters was, however, too heavy, rigid, and cumbersome for a traverse, and could only be safely loaded and unloaded off the sled with a forklift. It is recommended that a light-weight structure with a collapsible roof (like that found in some RVs) be designed. The structure should be permanently attached to skis and should fit into a C-130. Alternatively, the field party should be divided to several independently-moving teams of 2-4 people sleeping and cooking in tents. This second option would make the management of the project difficult, and would result in redundancy of field equipment.

3. Other lessons: Apart from the advance survey team, the only two people working outside and unprotected from the wind were the person behind the plow and the shooter.

Oxygen deprivation and carbon monoxide poisoning did not occur during the experiment.

Logistics

1. Caches: A major problem of any traverse is planning the caches. Caches were placed in advance of the experiment by a Twin-Otter aircraft with quantities based upon a certain rate of daily progress. However, when these rates were not met due to bad weather, technical, or mechanical problems, it was necessary to shuttle tens of km (24-60 hours round-trip) to either bring more fuel and food or to clear unused caches. The only alternative is to have Twin-Otter support on demand. However, this alternative can also result in delays if the twin-otter cannot fly due to weather or mechanical problems. In general, cache planning for EAST93 was good, except for the first cache (at the beginning of the line) where we spent longer than anticipated assembling and preparing the equipment for work.

2. Explosive airdrop: Airdrop of explosives by RNZAF C-130 flying from Christchurch en-route to McMurdo was highly successful. Explosive palettes landed within 50 m of the caches. Explosives were not damaged and did not pose any risk for later usage. Removal of parachutes and palettes by Twin-Otter immediately after air drop was helpful.

3. Other lessons: Air support by both VXE-6 C-130 and the Twin-Otter aircrafts and coordination by USAP were timely, efficient, and professional.

Communication via MacOps was excellent and response to logistical requests over the radio was timely.

Mechanical Aspects

1. Generators and batteries: NZAP supplied diesel generators (2.5 to 5 kW) that ran on JP-8. Three of the 4 generators failed for a variety of reasons. In addition, their output in the high altitude of the plateau was 40% of that expected at sea level. All generators quit working or were shut down to avoid damage during storms involving blowing snow. It is recommended that only Mogas generators be used and that they should be housed in a portable protective shack. Alternative energy sources should be explored, because the plateau is generally sunny and has steady winds. Mixing 230V and 110V power supplies (due to the joint US/NZ nature of the event) was inconvenient. A thought should be given to connecting the seismic recording system directly to the Hagglund battery to save on battery charging, because the seismic recorder is the largest consumer of battery power.

2. Starting vehicle engines: Starting the Tucker vehicles in the cold temperatures and winds prevailing on the plateau was a lengthy and an energy-consuming process. This was not the case with the Hagglund whose engine is completely enclosed. The construction of a transparent (Plexiglas) shelter to protect and passively warm the Tucker engine is recommended. Alternatively, a chemically-based heater (akin to hand warmers) should be supplied to be put on the engine block overnight.

3. Fuel consumption: Fuel consumption for all vehicles was on average 1.5 times greater than at sea level (for exact numbers see Appendix 8).

4. Sleds: The Maudheim and 1-Ton sleds were ideally suited for the traverse. Their size and their carrying weight are small enough to handle crevasse and sastrugi areas. They can be lifted and dragged by several people. Most important, they are low enough to the ground that fuel drums and other heavy loads can be dragged onto them. Their major disadvantage is that their frames are not strong enough to hook several of them in a row. The lack of

strong frames limits the possibility of having a bulldozer tow a train of several Maudheims. The larger Anare sled was strong enough to tow other sleds behind it but was too high off the ground to load fuel drums, a broken skidoo, etc.

Rate of progress
1. The daily speed of traverse without carrying out seismic work was only 2-3 times faster than a traverse while carrying out seismic work. All large vehicles traveled only in first gear because of the surface conditions and the load they were pulling. Sastrugi were encountered along 60% of the traverse, some of them up to 1.5m high. The sastrugi did not cause any particular problems except to slow vehicle movement (1-2 km/h instead of 3-4 km/h for the large vehicles). We opted not to move in areas of sastrugi when ground definition was poor, to avoid damage to vehicles.

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REFERENCES

Barrett, P.J. and Froggatt, P.C.,1978, Densities, porosities, and seismic velocities of some rocks from Victoria Land, Antarctica, *N.Z. J. Geol. Geophys.*, 21, p. 175-187.

Crary, A.P. 1963. Results of United States Traverses in East Antarctica, 1958-1961. *IGY Glaciological Report*, Number 7, December 1963. World Data Center A : Glaciology, American Geographical Society, New York, 35 p.

Drewry, D.J., 1982, Ice flow, bedrock, and geothermal studies from radio echo-sounding inland of McMurdo Sound, Antarctica, *in*: C. Craddock (Ed.), *Antarctic Geoscience*, Madison, University of Wisconsin Press, p. 977-983.

Drewry, D.J., Jordan, S.R., and Jankowski, E., 1982, Measured properties of the Antarctic ice sheet: Surface configuration, ice thickness, volume, and bedrock characteristics, *Ann. Glaciol.* 3, p. 83-91.

Drewry, D.J. (ed.), 1983, Antarctica: *Glaciological and geophysical folio*, Cambridge, U.K., Scott Polar Research Institute, 9 sheets.

Elliot, D. H., 1991. Triassic-Early Cretaceous evolution of Antarctica, *in* M. R. A. Thomson, A. Crame and J. W. Thomson, ed., *Geological evolution of Antarctica*: Cambridge, Cambridge University Press, p. 541-548.

Grootes, P.M. and Steig, E.J., 1992, Taylor Dome ice-core study, *Antarctic J. U.S.*, 27(5), p. 57-59.

McElroy, C.T., and Rose, G., Geology of Beacon Heights, Southern Victoria Land, Antarctica, 1:50,000, *New Zealand Geological Survey Miscellaneous Series map 15 (1 sheet) and notes*. Wellington, DSIR.

Melhuish, A., Bannister, S., ten Brink, U., Beaudoin, B., Stern, T., 1993. Seismic experiment Ross Ice Shelf 1990/91: characteristics of the seismic reflection data. *Institute of Geological and Nuclear Sciences Science Report 93/6*, 45p.

Morse, D., and Waddington, E., 1992, Glacier geophysical studies for an ice-core site at Taylor Dome: Year two, *Antarctic J. U.S., 27(5)*, p. 59-62.

Stern, T. A. and U.S. ten Brink, 1989. Flexural uplift of the Transantarctic Mountains: *J. Geophys. Res.*, 94, p. 10,315-10,330.

ten Brink, U.S., Bannister, S., Beaudoin, B.C., and Stern, T.A., 1993, Geophysical investigations of the tectonic boundary between East and West Antarctica, *Science*, 261, 45-50.

Webb, P. N., 1991. A review of the Cenozoic stratigraphy and paleontology of Antarctica, *in* M. R. A. Thomson, J. A. Crame and J. W. Thomson, ed., *Gelogoical Evolution of Antarctica*: Cambridge, Cambridge University Press, p. 599-607.